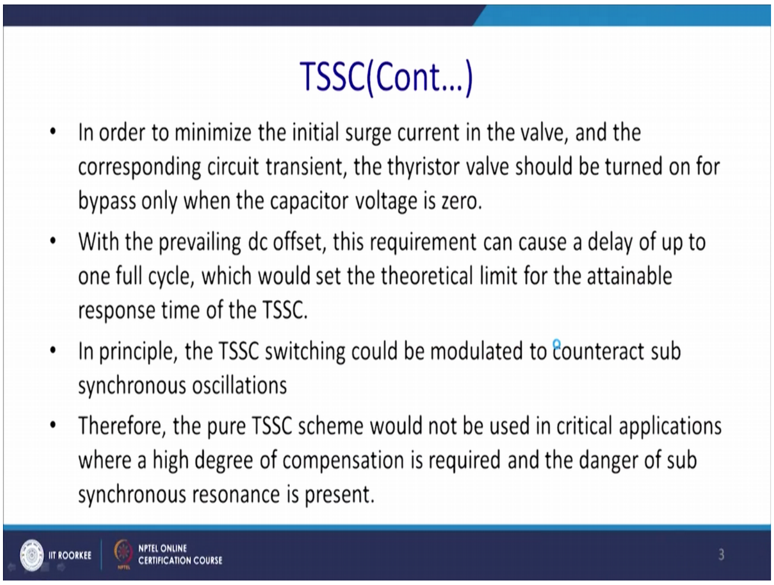
Flexible AC Transmission Systems (FACTS) Devices
Dr. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 26
TSSC II and TCSC I

Welcome to our NPTEL lectures on Flexible AC Transmission FACTS Devices, we shall continue with our discussion on TSSC followed by we will discuss about TCSC we will try to close both this unit in today's half an hour's lecture. So, we have, we have to deal with this two entities here now. So, let us go to the topic where we have left. So, we were discussing about TSSC.

(Refer Slide Time: 01:01)



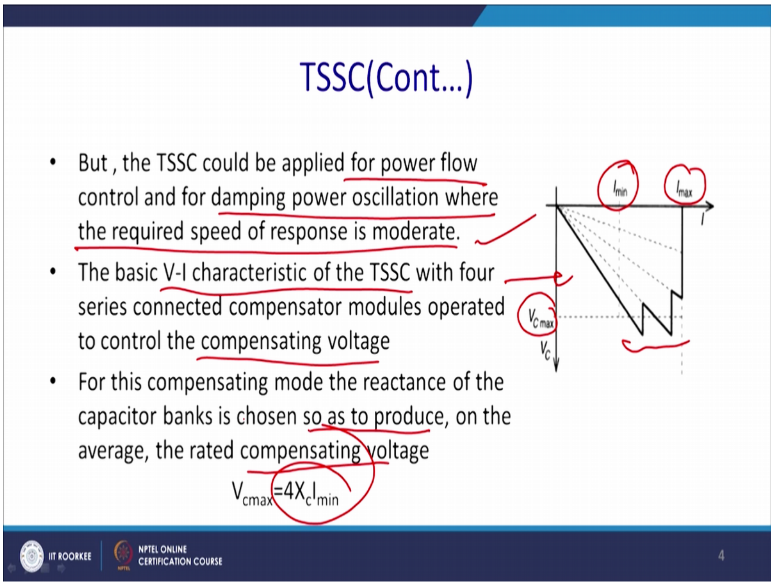
So, I am the control intern and control technique, in order to minimize the initials surge current in the valve and the corresponding circuit transient; the thyristor valve should be turn on or bypass only when capacitor voltage is received.

So, you have to see that and we are require to do it. So, how to do that with the prevailing DC offset this requirement can cause a delay up to a full cycle, because you have seen that there is a DC offset will be there in case of this TCSC, which would set theoretically the limit for the attainable response time of the TCSC. So, there will be a delay till the voltage across this devices become 0, in principle TCSC switching could be modulated to counteract the sub synchronous oscillation. So, you can damp out in a such a way the current through the system in such a way that will damp out the sub synchronous impedance.

Therefore, pure TCSC scheme could not be used in a critical application, where high degree of compensation is required and the danger of the sub synchronous reactance are present. Because we are inserting the capacitor essentially that may lead to reduce the value of the impedance and if it is insertion is slow that leads to the sub synchronous impedance and ultimately you got a delay at least half a, at least actually one of cycle.

So, thus you know it is not advisable to use only the TCSC as a series compensation it can be combinations of the GCSC TCSC, it can be combination of the SSSC which we were discussed that is a versatile device with that it can be coupled. So, since it is thyristors its control has got lot of limitation.

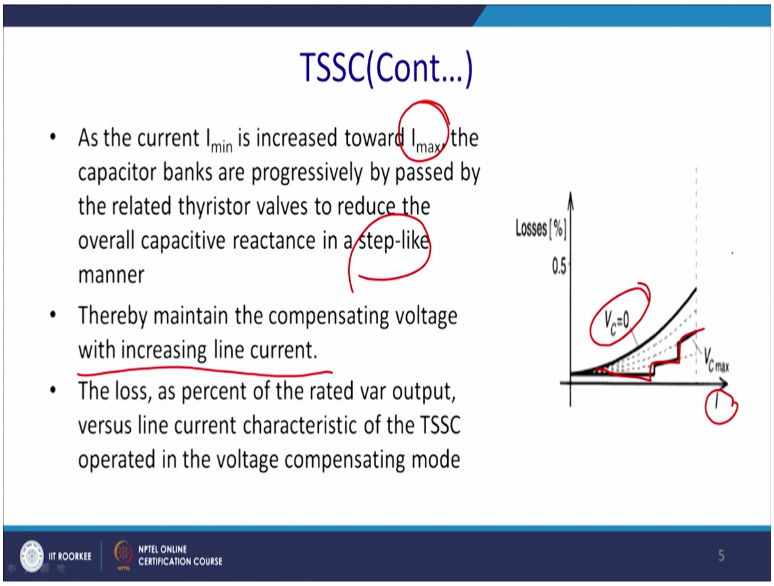
(Refer Slide Time: 03:37)



But this TSSC could be applied for the power flow control and for damping power oscillation where required speed response is moderate. So, this is the where it can find its application, you say this is the V Cmax the maximum V C can be applied and this is the I V characteristics. And accordingly this value can be changed, this is I max and this is I min within the range you can operate you can choose any value of the admittance.

The basic V I characteristics of the SSC with the four series connected compensated module operate to control the compensating voltage has been shown this figure. For this compensation the mode of reactance of the capacitor bank is chosen as to produce on the average rated compensating voltage that is this value V C max is basically 4X c into I min.

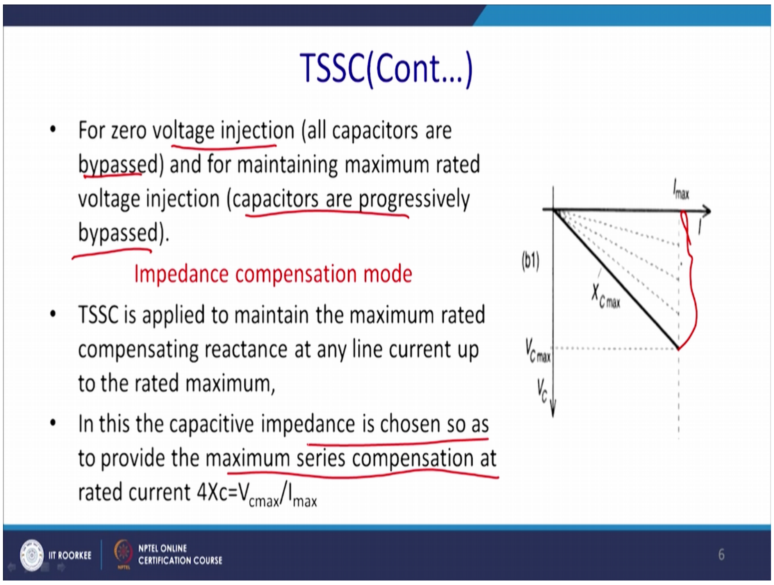
(Refer Slide Time: 05:01)



So, what happens then as a results when I min is increased towards I max so, losses will increase definitely. The capacitor banks are progressively by passed by the by the, by the thyristor valve to reduce the overall capacitance and the in a spike like manner. So, you had a, for this is in you have this kind of spikes in admittance, thereby, you maintain the compensation voltage with increase in current limit.

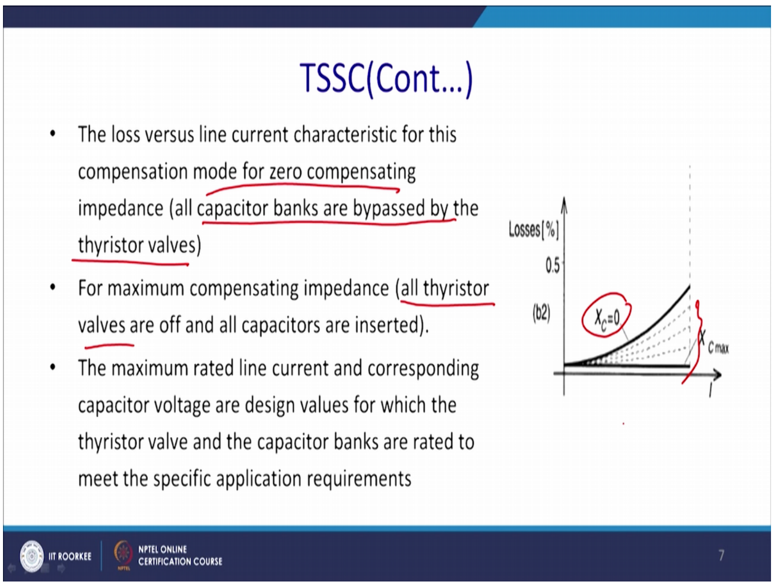
Since, you are changing the impedance of the line current limit may touch and thus also the loss. So, ultimately you will have this kind of thing, this is the way it will change and this is the case of V C equal to 0 and thus you have bypass all the thyristors, all the capacitor. And thus, thyristor is switched so the thyristor losses will account and current, if current is more this will increase in a parabolic manner. The loss percent of the rated var output versus line current characteristics of the SSC operated in the voltage compensating mode so this is there.

(Refer Slide Time: 06:33)



For zero voltage injection all capacitors are bypassed and for maintaining maximum rated voltage injection capacitor are progressively bypassed. So, ultimately one after another capacitor can be bypassed. So, let us see that compensation, impedance compensation mode. So, this is basically X this is I and this is V and this is actually the maximum curve and ultimately TSSC has to operate in this zone, in this capacitive impedance is chosen. So, as to provide maximum series compensation at rated current four X C equal to V C max by I max.

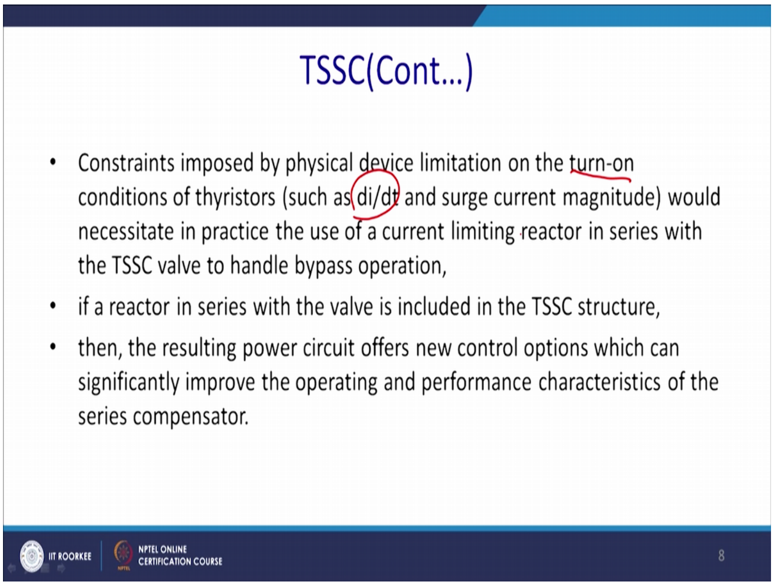
(Refer Slide Time: 07:24)



The loss versus line current characteristics for this compensation mode for the 0 compensating impedance, all capacitor banks are bypassed by the thyristor valve. For maximum compensating impedance all thyristor valves are off, all the capacitors are inserted. So, this is the losses, you know this is for X C equal to 0 you will have maximum losses, gradually over it is bypassed so, switching losses will come down gradually.

The maximum rated current and corresponding capacitor voltage are designed value for which the thyristor valve and the capacitor banks are rated to the, rated to meet the specific application requirement. So, we have to choose a properly the DC capacitor voltage and the value of the capacitor, constraint imposed by the physical device limitations on turn on condition of the thyristors.

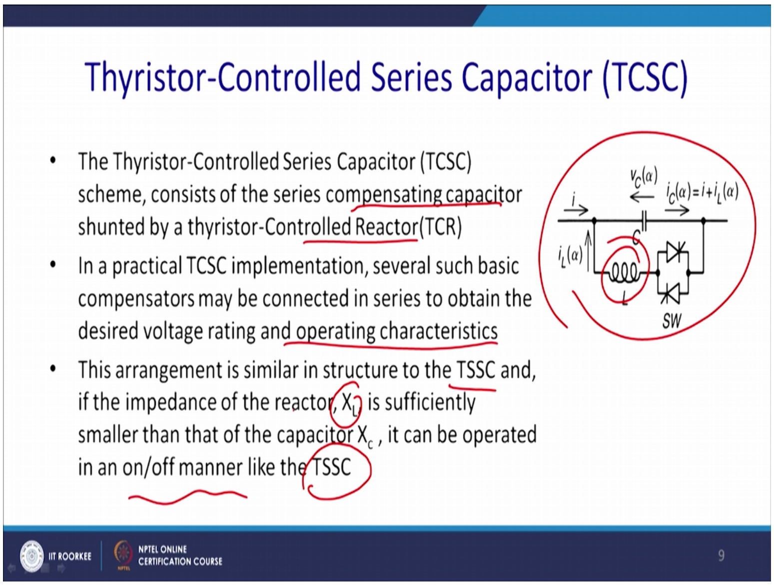
(Refer Slide Time: 08:37)



Such as di dt protections of the surge current magnitude would necessitate in practice to use a current limiting reactor, for this is it is not only capacitor, there will be a current limiting device that will give you di dt protection, in series with the TCSC valve to handle the bypass operation. Because if the capacitor discharged with the thyristors, high current will flow through the thyristor with high di dt that may damage thyristor.

If reactor in series valve is included in the TCSC structure then the resulting power circuits offers new control operation which significantly improve the operation and the performance characteristics of the series compensator. So, we have, it is advisable to put a series reactor with TSSC. So, for this reason this become the actual circuits, mainly is this purpose is to you know limit the di dt across this thyristor.

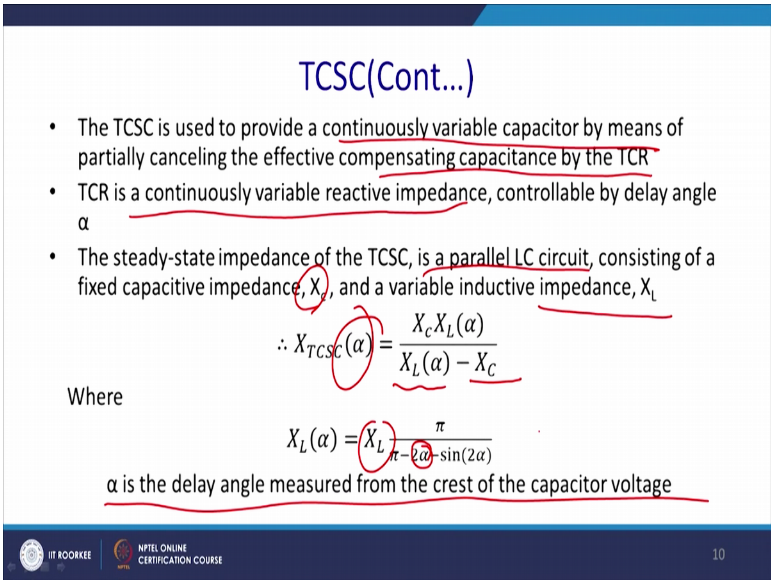
(Refer Slide Time: 09:57)



This thyristors controlled series capacitor so, it is a improved version of the previous version of TSSC, the thyristors controlled series capacitor TCSC scheme consists of the series compensating capacitor shunted by the thyristor controlled reactor. So, you will have a inductor here, in practical TCSC implementation several such basic [com/compensator] compensator may be connected in series to obtain the desired voltage rating and the operating characteristics.

So, it can be put, actually put into the modulate form and series, this arrangement similar structure of the TSSC that we have discussed here and if the impedance of the reactor X L is sufficiently smaller than that of the X C, it can be operated in on off manner like you know previously discussed TSSC. Now, so what will be its reactance?

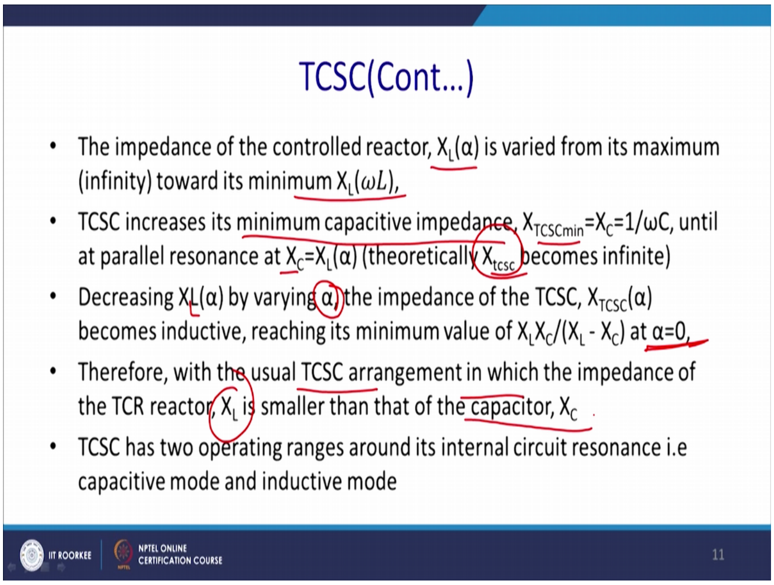
(Refer Slide Time: 11:19)



The TCSC is use to provide a continuously variable capacitor by means of partially cancelling the effective compensating capacitance by TCR. TCR is a continuously variable reactive impedance controlled by the delay angle alpha, this steady state impedance of the TCSC is a parallel LC circuits consisting of a fixed impedance X C and the variable impedance X L.

So, overall impedance is given by, it will be controlled by alpha X C X L alpha, X L minus X C. So, that gives you X L alpha equal to X L by pi, pi minus 2 alpha minus sin alpha, alpha is a delay angle measured to the crest of the capacitor. So, this is the expression where actually you can compute the amount of the X L, in accordingly you can compute the firing angle of the thyristor, please note that this has to be solve since there is a alpha and sin alpha. So, this equation has to be solved by the iterative method. So, what are the actually characteristics of the TCSC we can say how to calculate alpha.

(Refer Slide Time: 12:56)

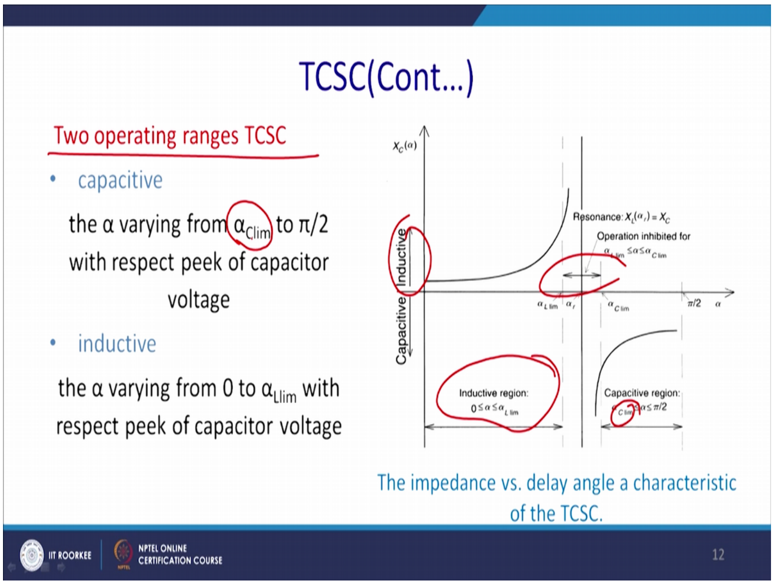


The impedance of the controlled reactor X L alpha is varied from its maximum to the infinity towards minimum X L. The TCSC increases its minimum capacitive impedance that is TCSC minimum equal to X C equal to 1 by omega C until the parallel resonance at X C equal to X L alpha and theoretically it becomes infinite, so thus it can offer a huge impedance.

Decreasing X L sorry, it should be suffix alpha by varying the triggering angle the impedance of the TCSC that is X TCSC alpha becomes inductive and reaching maximum value for X L into X C by that is a combination of it X L minus X C at alpha equal to 0. Therefore, with the usual TCSC arrangement in which the impedance of the TCR that is X L is smaller than the capacitor X C. Otherwise, this condition may prevail and you will offer actually infinite impedance and thus no current will flow through the transmission network.

So, TCS, so TCSC has two operating ranges around the internal circuit resonance; that means the capacitive mode and the inductive mode. So, you should have both the mode possible and that has that flexibility is given here and this mode is inductive mode.

(Refer Slide Time: 15:01)

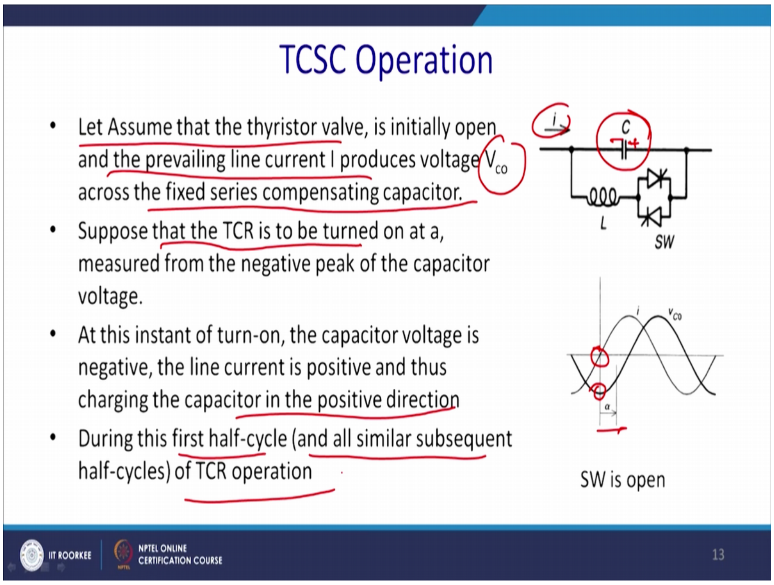


You can change with the alpha and here is the region where you can change alpha angle actually triggering angle. So, it is equal to 0 to minimum alpha, similarly the C limit will change, alpha C limit will change accordingly. So, when it will be capacitive, this is a two mode of operation in TCSC the alpha varying from I C alpha minimum or limit to pi by 2 with respect to the peak of the capacitor voltage.

Similarly, you will have a inductive alpha for alpha varying actually for the 0 crossing of the voltage, 0 to alpha minimum with respect to the peak of the DC capacitor voltage. Thus, this is the characteristics in the inductive characteristics, this can change to alpha 0 to alpha minimum and here it can change to alpha to pi by 2.

So, this is the actually the alpha value you can chosen for the capacitive, if you wish to have a capacitive region you have to restrict alpha with this region, if you wish to operate in inductive region to increase the inductance of the circuit you have to choose this alpha. So, let us see that V I characteristics actually the reforms of the TCSC.

(Refer Slide Time: 16:44)

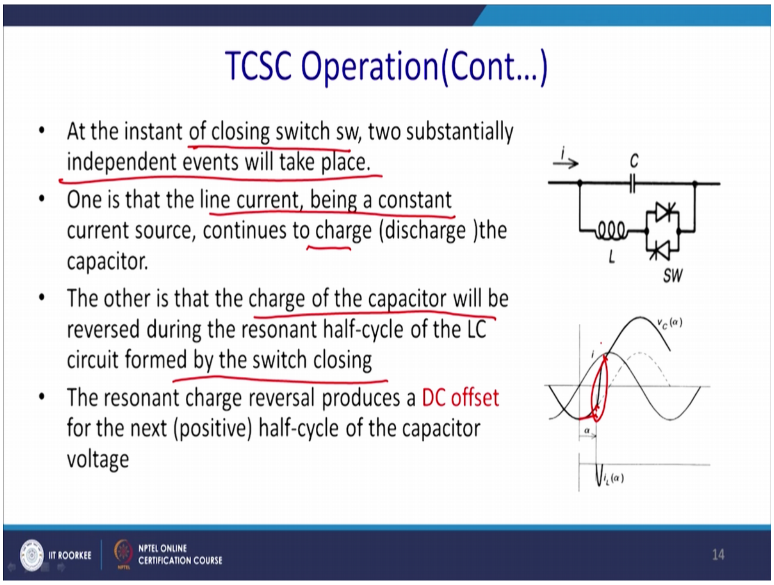


Let us assume that the thyristor valve is initially open. So, all the current was passing through the capacitor and thus what happen, and the prevailing line current produces the voltage V C0 across the fixed compensated capacitor, so across this device.

Now, we shall trigger it, suppose that the TCR is to be turned on at a measured from the negative peak voltage of the DC capacitor, so this is the value of the DC capacitor and this is the delay angle alpha. At this instant on turn on the capacitor voltage is negative and also you can see that line current going to be positive and thus charging the capacitor in opposite direction.

So, it will charge the capacitor because you know polarity, this current you can taken a positive polarity so ultimately you got this. So, in that moment you have fire the thyristor and thus it will actually charge the capacitor in opposite direction. During the first half cycle in a similar subsequent half cycle of the TCR operation.

(Refer Slide Time: 18:17)

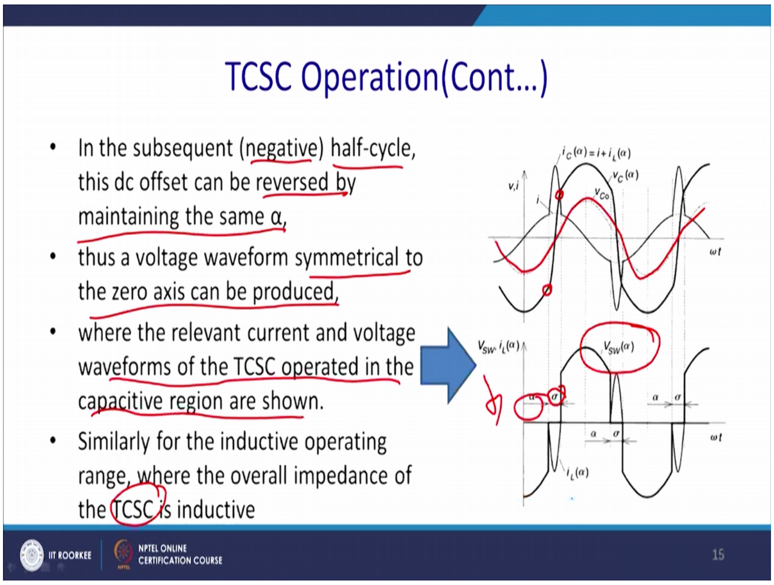


So, what is a advantage of it? So, see that what happen here. So, this is the V C all of a sudden there will be a sudden jump from there you get an alpha, so here its thyristor has been triggered. So, it will be jumping out to the minus V C to, actually some voltage of negative voltage to the same magnitude of the positive voltage.

At this instant the closing switch SW, two subsequently independent event will take place so this transient has to be controlled. So, we have to understand this actually the voltage current characteristics of this thyristors, one is that the line current being a constant current source continues to charge or discharge depending on a different cycle of the capacitor.

The other is that, the charge of the capacitor will be reversed during the resonant half cycle of the LC circuit formed by switching or the switch closing. So, it will be jumping out from this point to this point, and thus what happen? The resonance charge reversal produces are DC offset, for the positive half cycle and the half cycle of the capacitor voltage. So, you will have a DC component comes into the picture.

(Refer Slide Time: 19:55)

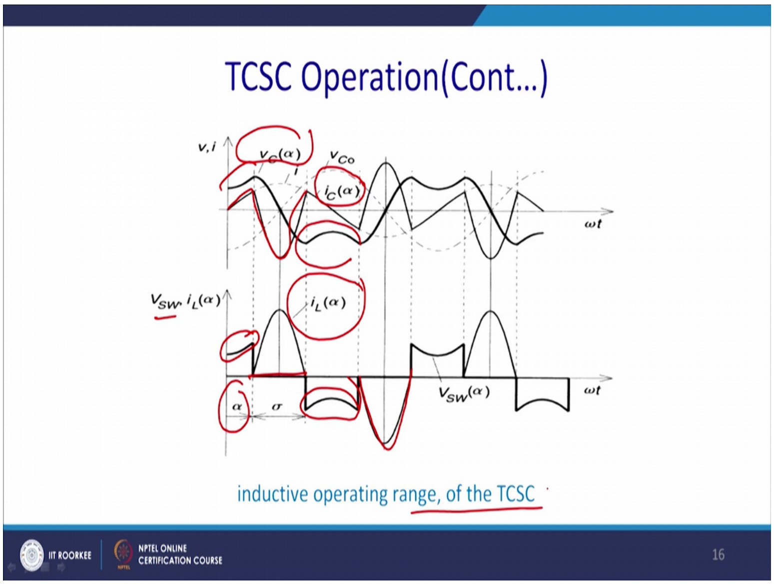


So, this is the overall characteristics, let us see. So, this is the V C, V C alpha that would have been here without the triggering, once you trigger what happen you know actually this is the V C alpha. So, since it has got a DC offset it will shift like this, then it from here it will be actually go like this and you will have this kind of characteristics, huge DC swing will be there.

Let us understand this curve, this subsequent negative half cycle the DC offset can be observed by the magnitude of angle, same angle alpha, let us see that. Thus the voltage waveform symmetrical to the 0 axis can be produced, the relevant current and the voltage waveform of TCSC operation in the capacitive regions is shown.

So, this is the alpha and this is a conduction angle sigma, see that you know and this is basically this voltage across the switch and. So, this is the switch and i alpha similarly for the inductive operation, this is the lower one, upper one is the capacitive operation, where TCSC where the overall impedance is inductive will we will see this characteristics and we will see its switching pattern.

(Refer Slide Time: 21:51)

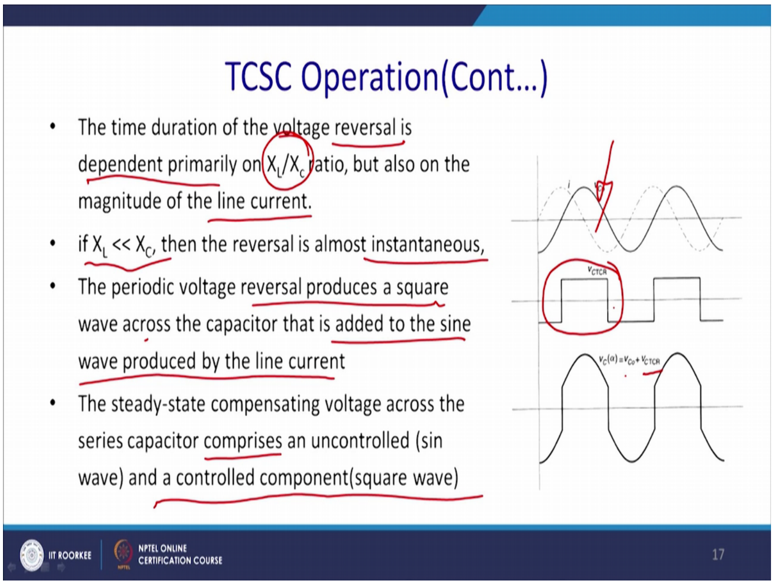


So, what happen, this is actually v i and this is actually v C alpha and these sinusoidal voltage is v C0 and this one is your V C alpha. So, we will have this kind of pattern and thus what happen after switching. So, you will find that till angle triggered alpha it will follow the same since it is connected parallel to the DC capacitor, connect to the capacitor.

So, it will have a fall the same voltage pattern then it is triggered, ultimately you will find i alpha and the voltage will be 0. Then thereafter what will happen here since there is no current, you will find current is 0 and you will have a thyristor voltage a V C switch will be same as the receivers voltage. And thereafter again it is when triggered and thus what happen you know you will have a current will flow same as the here.

So, accordingly it is a super imposition of the i SW and i L in the same way form and this is the zone of operation of the inductive operation of the TCSC.

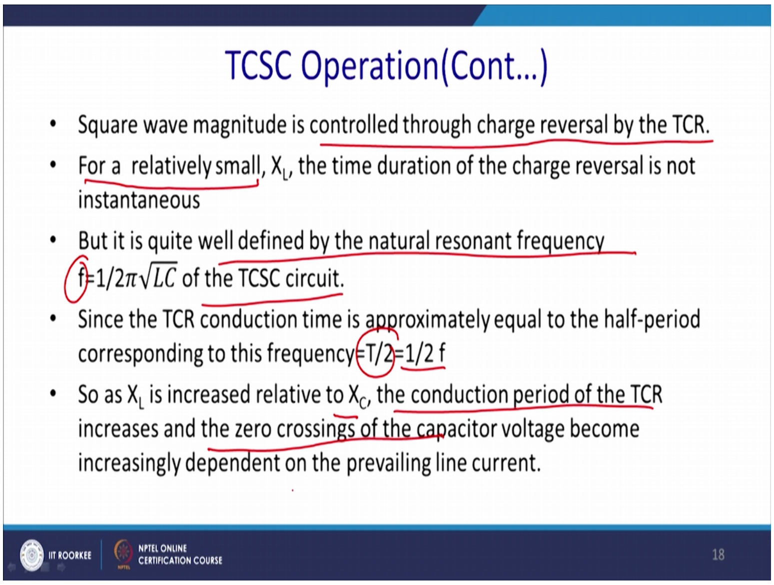
(Refer Slide Time: 23:16)



Now, what we can conclude from this graphs. the time duration of the voltage reversal is depending on these actually this ratio X L by X C, but also on the magnitude of the line current. The, that is X L is smaller than the capacitor X C then the reversal is almost instantaneous, the periodic voltage reversal produces a square wave across the capacitor that is added to the sine wave produced by the line current. So, you may have this kind of TCR and ultimately you can think of V C alpha is equal to V Co plus TCR. So, what happen? There will be a square wave and is super imposed by a sinusoidal waves.

So, thus you get this kind of characteristics, the steady state compensating voltage across the series capacitor compromise, actually comprises an uncontrolled sinusoidal wave and the controlled component of the square wave. So, this is the V Co and that is uncontrolled and this is actually V CTCR that is controlled. So, this imposition makes it actually V C alpha.

(Refer Slide Time: 24:57)



So, what we can say more about the TCSC. So, square wave magnitude is controlled through the charge reversal by TCR. For relatively small X L the time duration of a charge reversal is not instantaneous, it will take some time. But, it is quite well defined by the natural frequency of oscillation where f is basically 1 by under root of omega C; So, omega C under root of l c for the TCSC circuit.

Since, the TCR conduction time is approximately equal to the half period corresponds to the, this frequency that is T by 2 equal to 1 by f. So, you can choose the value of the X L, the value of the X L is increased related to the X C and the conduction period of the TCR increases and what happened then, the 0 crossing of the capacitor voltage become increasingly dependent on the prevailing line current. So, this is the actually the consideration, ok.

Thank you for your attention, we shall continue with the TCSC in our next class and we shall try to complete our all the series regulators in our next class discussion.

Thank you for your attention, thank you.